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1 Mangrove Area and Propagule 2 Number Planting Targets Produce 3 Sub-Optimal Rehabilitation and 4 Afforestation Outcomes

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11 **ABSTRACT**

12 Mangrove rehabilitation projects often fail completely or fail to meet their objectives.
13 This study examines village-level rehabilitation planting carried out in 13 villages
14 (119 rehabilitation attempts at 74 sites) across two countries in southeast Asia, to
15 assess village-level rehabilitation effectiveness, and to identify what factors
16 influenced outcomes. Mean propagule survival across all rehabilitation attempts was
17 20% with a median of 10%. Sixty six percent of attempts had a survival rate of less
18 than 20%. Mid mangrove zone projects were more successful (mean 30%) than
19 rehabilitation projects at other elevations. Planting on mudflats, representing 32% of
20 rehabilitation / afforestation attempts, achieved only a 1.4% propagule survival rate.
21 The overall low success rate was due to several inter-related factors. Poor
22 site/species matching on high and low elevation sites was common; for example,

23 *Rhizophora* spp. was used alone or in combination at least 65% of the time,
24 including on mudflats where this genus is ecologically unlikely to establish. Site
25 selection was often driven by the desire to achieve centrally defined area or
26 propagule *planting* targets, rather than *survivorship* targets, and thus required large,
27 uncontested project areas. Conversely, the presence of natural regeneration, even if
28 in small amounts, was associated with higher than average success. Therefore, it
29 was estimated that only 16% of planting attempts were actually necessary.

30 ***Highlights***

- 31 ● Mean survival of all mangrove rehabilitation planting attempts was 20%,
32 median 10%
- 33 ● Only 16% of planting attempts deemed necessary vs. natural recruitment
34 potential
- 35 ● Better hydrological connection significantly improved survivorship (mid/high
36 zones)
- 37 ● Area or propagule planting targets should be changed to survivorship targets

38 ***Keywords:*** mangrove restoration, mangroves, failure, survivorship, area target,
39 planting target, Thailand, Philippines

40

41 **1. Introduction**

42 **1.1 Mangroves are Particularly Beneficial to the Poorest Coastal** 43 **Villagers**

44 Mangroves form highly productive ecosystems, (Alongi, 2009) which provide many
45 direct and indirect benefits and services (Moberg and Rönnbäck, 2003; Saenger,
46 2002; van Oudenhoven et al., 2015). These services are particularly valuable and
47 relevant to the poorest members of coastal villages (Glaser and da Silva Oliveira,
48 2004; Kairo et al., 2001; Springate-Baginski and Than, 2011; Stevenson et al., 1999;
49 Sunderlin et al., 2005). They include a nursery function for fish and shrimp (Saenger
50 et al., 2013; Salmo III et al., 2018) and provision of wood for construction and fuel for
51 cooking (Moberg and Rönnbäck, 2003).

52 **1.2 Mangrove Losses Declining, but Measurement is Challenging**

53 In previous decades, management of mangrove loss has proved challenging. This
54 was as a result of low-resolution remote sensing imagery and of classifying
55 mangrove as opposed to other types of vegetation. Furthermore, there has been a
56 lack of a definitive methodology for identifying and classifying 'mangrove' at different
57 levels of degradation and canopy cover (Giri et al., 2011; Hamilton and Casey,
58 2016). Within the 21st century, global losses have been reported to be 0.16% -
59 0.39% per year, indicating a slowing of the rate of loss from the 1980s (0.99%) and
60 1990s (0.7%) (Hamilton and Casey, 2016).

61 Southeast Asia has historically seen some of the greatest losses. For example,
62 mangrove cover in the Philippines has fallen from 450,000 ha in 1900 to 120,000 ha
63 in 1995 but the rate of loss has slowed to 0.1% per year since 2000 (Long et al.,
64 2014; Primavera and Esteban, 2008). In Thailand, using 1961 as a baseline, less

65 than half of all the mangroves remain (Aksornkoe, 2004). From 2000 - 2012, Thai
66 losses were 0.69% per year (Hamilton and Casey, 2016).

67 **1.3 Mangrove Rehabilitation Initiated for Many Reasons and by a** 68 **Variety of Actors**

69 Following natural disasters such as the Indian Ocean tsunami of 2004 and cyclone
70 Haiyan / Yolanda in the Philippines, and to recover some of the goods and services
71 provided by mangroves, there have been significant efforts to rehabilitate areas of
72 converted or degraded mangroves (Aung et al., 2011; Primavera et al., 2011;
73 Primavera and Esteban, 2008). This effort has included attempts to afforest new
74 areas that were previously not inhabited by mangroves. Most often, governments
75 have commissioned mangrove rehabilitation programs through forestry and
76 environment departments, which in turn have sometimes engaged local villages to
77 assist. Occasionally, communities and villages have initiated their own rehabilitation
78 projects. Examples include Pred Nai in Thailand (Fisher, 2000; Senyk, 2005) and
79 Myanmar (Springate-Baginski and Than, 2011). There are also reports of
80 rehabilitation by individuals within coastal villages, in the Philippines (Walters, 2004,
81 2000, 1997; Walters et al., 2005) and Thailand (pers. obs.).

82 **1.4 'Restoration' or 'Rehabilitation'?**

83 The scientific literature often uses 'restoration' and 'rehabilitation' interchangeably
84 (van Oudenhoven et al., 2015) or uses other words including repair, reclamation,
85 reforestation, conservation, afforestation or eco-development (Duke, 1996).

86 Restoration might be defined as recovering an area back to an assumed original
87 'pristine' ecosystem, implicitly including the restoration of mangrove functionality
88 (Kairo et al., 2001; Stevenson et al., 1999; Walters et al., 2008). However, the word

89 is often used more broadly (McDonald et al., 2016). Rehabilitation is an attempt to
90 recover *some* of the ecosystem functions or to find another stable use for the land
91 (McDonald et al., 2016; Stevenson et al., 1999; Walters, 2008; but see Field, 1999a).
92 The debate concerning these terms continues (see Dale et al., 2014 for a review).
93 While acknowledging this debate, and the need for clarity of definition for legal
94 purposes and for setting expectations (Dale et al., 2014), this paper will use the term
95 rehabilitation. Similarly, care is needed when describing areas as ‘degraded’,
96 because the perception of whether an area is partially degraded or not is affected by
97 cultural expectation and land management intensity (Hobbs, 2016). Furthermore,
98 changes to an ecosystem’s state may be adjustments beyond those caused by
99 normal forest growth and development processes, leading to a new equilibrium as a
100 result of climate change or long-term variation of weather patterns (Hobbs, 2016;
101 Mansourian et al., 2017).

102 **1.5 What is ‘Successful’ Rehabilitation?**

103 In principle project outcomes should be assessed in relation to stated project
104 objectives, and this is crucial in the planning of any mangrove rehabilitation work
105 (Field, 1999b; Lewis, 2000; Saenger, 2002). When viewing rehabilitation outcomes
106 from a narrow standpoint, ‘success’ may be claimed after five to seven years,
107 because this indicates probable long-term survivorship (i.e. to reproductive maturity)
108 and eventual (re)establishment of a mangrove stand (Bosire et al., 2008; Kodikara et
109 al., 2017). Salmo III et al., (2013) focused on vegetation and soil parameters in a
110 study of monospecific plantations. Their study suggested that mangrove ecosystem
111 stability might be reached by 11 years, and that ecological characteristics resembled
112 natural mangroves after 25 years. Other indicators of success have focused on the
113 whole ecosystem and consider that success can be claimed when the hydrological

114 normality of a mangrove has returned (Asaeda et al., 2016). Alternatively
115 rehabilitation assessment might compare project sites to natural mangroves
116 (McDonald et al., 2016) but not in terms of succession (Ellison, 2000). Despite
117 sometimes being an appropriate long-term measure, comparing project sites to old-
118 growth mangroves is particularly difficult in countries such as Thailand and the
119 Philippines. This is because much of the natural mangroves have been cut-over for
120 charcoal or fuelwood and replanted with a less diverse range of species (Alongi,
121 2002). Resources permitting, a more comprehensive approach is an *ecological*
122 *rehabilitation* perspective (the literature often uses *restoration* in this case) (Asaeda
123 et al., 2016; Ellison, 2000; Lewis, 2005; Walters et al., 2008). This approach looks for
124 the return of full ecosystem function, including outflow of organic material to, and
125 habitat connectivity with, linked seagrass and coral systems. This can be relatively
126 complete within five years (Saenger et al., 2013).

127 While social factors are pertinent, here we focus on a strictly biological (or
128 silvicultural) definition of success – whether planted seeds / propagules survive to
129 establishment.

130 **1.6 Rehabilitation and Afforestation Successes and Failures**

131 There have been positive mangrove afforestation survivorship outcomes in
132 Bangladesh (Saenger and Siddiqi, 1993, but see Moberg and Rönnbäck, 2003) and
133 successful mangrove rehabilitation in Florida (Brockmeyer et al., 1996; Lewis, 2005;
134 Lewis and Gilmore, 2007), Philippines (Asaeda et al., 2016; Primavera et al., 2012;
135 Walters, 2004) Indonesia, (Lewis and Brown, 2014) and Myanmar (pers. obs.).
136 However, many rehabilitation projects fail completely or do not achieve their
137 objectives (Elliott et al., 2016; Erfemeijer and Lewis, 1999; Field, 1996; IUCN, 2017;

138 Lewis, 2005; UNEP, 2007) or at best produce limited positive results (Alongi, 2002;
139 Aung et al., 2011; Barbier, 2006; Ellison, 2000; Memon and Chandio, 2011; Moberg
140 and Rönnbäck, 2003). Mangrove rehabilitation projects that have become
141 established often resemble even-age class, mono-specific plantations rather than
142 natural mangrove (Bosire et al., 2006; Ellison, 2000; Field, 1996; Lewis, 2005),
143 bearing little or no similarity to the original mangrove (Alongi, 2002). In addition they
144 exhibit only limited species zoning and biodiversity (Bosire et al., 2008). However, of
145 greater immediate concern are the often extremely low propagule survival rates of
146 these rehabilitation programs.

147 Sanyal (1998) reported that in West Bengal more than 9,000 ha were planted with
148 only 1.5% probable survival. In the Philippines, despite significant efforts and
149 financial inputs over the last twenty years, survival of planted mangroves remains
150 low at 10-20% (Primavera, 2015; Primavera and Esteban, 2008; Samson and
151 Rollon, 2008; Walters, 1997). Similar conclusions have been drawn from Sri Lankan
152 rehabilitation programs (Samarakoon, 2012).

153 **1.7 Technical Reasons for Previous Failures**

154 Why do so many rehabilitation projects fail? Here we consider the suggestion that
155 the most common technical reason for planting failure is poor site/species matching,
156 i.e. choosing an unsuitable species to plant for a given site (Aung et al., 2011; Bosire
157 et al., 2006; Lewis et al., 2016; Primavera and Esteban, 2008; Walters et al., 2008).
158 What is meant by unsuitable? Individual species have differing tolerances to specific
159 biogeochemical factors and gradients present across the intertidal area (Saenger,
160 2002). These include salinity, soil type, soil anoxia, sulphate levels, nutrient levels,
161 pH, wave energy, temperature, light levels, inundation regimes (Alongi, 2009;

162 Tomlinson, 2016; van Loon et al., 2016), tides and wind distribution of propagules
163 and seeds (van der Stocken et al., 2012), and species-selective predation by
164 herbivores (Elster, 2000; Sousa et al., 2003). Species therefore exhibit differing
165 'preferences' for elevation and location within the intertidal zone (Duke, 2006;
166 Snedaker, 1982; Tomlinson, 2016).

167 Closely related to site/species matching is poor site choice. Insufficient regard is
168 often given to understanding local hydrology, topography relative to sea level, and
169 the effects these have on soil conditions. These features greatly affect planting
170 outcomes (Aung et al., 2011; Elster, 2000; Hashim et al., 2010; Kairo et al., 2001;
171 Lewis, 2005). Duration of inundation is particularly important (van Loon et al., 2016).
172 In some cases rehabilitation can be achieved simply by reconnecting or improving
173 site hydrology, e.g. by installing culverts under a road, reconnecting former
174 aquaculture ponds or reopening lagoons (Brown et al., 2014; Elster, 2000; Ferreira
175 and Lacerda, 2016; Lewis, 2014; Twilley et al., 1999). In contrast, sites that have an
176 elevation below that of a natural front mangrove fringe are likely to have permanently
177 saturated soil with poor drainage, leading to anoxic and potentially acidic soil
178 (Holguin et al., 2001; Kristensen and Alongi, 2006). These factors have a significant
179 negative impact on the outcomes of projects attempting to afforest mudflats and
180 seagrass beds (Asaeda et al., 2016; Samson and Rollon, 2008; Stevenson et al.,
181 1999).

182 Many rehabilitation projects start planting first without fully understanding the original
183 cause of mangrove loss or why there is no natural regeneration on site (Asaeda et
184 al., 2016; Lewis, 2005, 2000; Walters et al., 2008). Both of these factors might be
185 mitigated by reducing and removing mangrove stressors specific to a site, such as
186 obstructed hydrology or unsustainable anthropogenic activities (e.g. harvesting of

187 mangrove wood) (Lewis et al., 2016). Other reported reasons for failure include
188 herbivore grazing and footfall damage, poor planting method, lack of aftercare (e.g.
189 weeding) and monitoring (Kodikara et al., 2017), barnacle infestation and high wave
190 energy (i.e. inappropriate site choice).

191 In this paper we describe a study of community-level planting projects to assess
192 survival rates and to identify factors that determine success or failure at the project
193 level.

194 **2. Materials and Methods**

195 **2.1 Location of Study Sites**

196 Although specific regional and local contexts are very important and highly variable,
197 multiple villages within two countries were studied in an attempt to produce some
198 general conclusions. Thailand and the Philippines share the same Indo-Malesia bio-
199 geo-climatic zone within the Indo-West Pacific (Duke, 2006; Tomlinson, 2016). They
200 have extensive mangrove areas, on which a substantial proportion of the coastal
201 inhabitants depend for their livelihoods and food (Balmford et al., 2002). Since 1945,
202 both countries have experienced significant mangrove conversion to aquaculture and
203 degradation for charcoal and fuelwood production, among other causes (Richards
204 and Friess, 2016).

205 Table 1 lists the Thai and the Philippine villages studied in this large-scale
206 investigation. This study combined ecological and social research to examine
207 mangrove rehabilitation in the context of biophysical, silvicultural and social factors.
208 Villages were chosen because they were located either within or near to an
209 extensive riverine mangrove delta or had a significant area of mangroves nearby. In
210 all cases mangroves were considered an important village resource and were used
211 in some ways by a substantial part of the village population. Finally, village
212 members had attempted mangrove rehabilitation or afforestation in the past. The
213 exception to these selection criteria was village P3A in the Philippines (Table 1)
214 which was included as it had conducted a record-setting '1 million propagules in an
215 hour' planting project (Escandor, 2012). Except for this final record-setting planting,
216 all Philippine planting discussed here was funded by the National Greening Program
217 (Department of Environment and Natural Resources, 2016), a large-scale bio-shield

218 establishment scheme initiated after typhoon Yolanda / Haiyan in 2013. Some
 219 rehabilitation or afforestation sites had been attempted more than once and each
 220 attempt was assessed. A site was defined as an individual plot or area villagers had
 221 attempted to rehabilitate or afforest as a discrete project. In total 119 attempts at
 222 rehabilitating 74 sites were assessed.

223

Table 1 Site information on mangrove rehabilitation projects evaluated in Thailand and Philippines

Thailand							
Village Number	1	2	3	4	5	6	
Village Code	T1A	T1B	T2A	T2B	T3A	T3B	
Approx. Lat Long	6.89° N 99.79° E	6.89° N 99.79° E	7.89° N, 99.16° E	7.89° N, 99.16° E	8.44° N, 99.96° E	8.44° N, 99.96° E	
Province	Satun	Satun	Krabi	Krabi	Nakorn Sri Thammarat	Nakorn Sri Thammarat	
Number of Rehabilitation Sites Assessed	13	11	9	6	5	3	
Village Mangrove Area (Ha) ¹	407	592	319	176	3,894	257	
Approximate Research Dates	Sept – Nov 2013	Dec 2013 – Feb 2014	Feb – May 2014	June – Aug 2014	Oct 2014 – Feb 2015	Feb – May 2015	
Philippines							
Village Number	1	2	3	4	5	6	7
Village Code	P1A	P1B	P2A	P2B	P2C	P2D	P3A
Approx. Lat Long	10.81° N, 119.5° E	10.81° N, 119.5° E	14.06° N 123.3° E	14.3° N 123.3° E	13.9° N, 123.2° E	14.0° N, 123.2° W	13.8° N, 122.8° E
Province	Northern Palawan	Northern Palawan	San Miguel Bay, Luzon	San Miguel Bay, Luzon	San Miguel Bay, Luzon	San Miguel Bay, Luzon	Camarines Sur, Luzon
Number of Rehabilitation Sites Assessed	10	8	3	3	1	1	1
Village Mangrove Area (Ha) ¹	126	856	Unknown	Unknown	Unknown	Unknown	NA
Approximate Research Dates	Sept – Dec 2015	Jan – Apr 2016	May 2016	May 2016	May 2016	May 2016	May 2016

1. Source: Local Dept. for Marine and Coastal Resources field offices (Thailand) and Dept. of Environment and Natural Resources field office (Philippines).

224

225 Many mangrove rehabilitation projects were attempted by Thailand's Department for
 226 Marine and Coastal Resources (DMCR) and the Philippine Department of
 227 Environment and Natural Resources (DENR) in the 1980s and 1990s. However, this
 228 study looked only at more recent planting from approximately 2007 onwards, which
 229 involved participation by local villages. Assessment of village P1A's (Philippines)
 230 rehabilitation ability was expanded because this village was commissioned by the
 231 government to plant not only within its own territory, but also in neighbouring villages.

232 All accessible P1A-rehabilitated sites were assessed because the planting team and
233 the techniques used were the same. Some rehabilitation was carried out in both
234 Thailand and the Philippines while the lead author was present in the village, (T1B
235 Jan 2014, T3A Dec 2014, Oct 2015) providing an opportunity to act as an observer
236 and witness techniques.

237 **2.2 Assessment Method**

238 **2.2.1 Initial Visits with Village Mangrove Expert**

239 During initial scoping interviews with villagers and village leaders, opinions were
240 sought to ascertain which resident was most knowledgeable about their mangroves.
241 In all villages consensus about a mangrove expert readily emerged, thus negating
242 the need to perform a village expert ranking exercise (Davis and Wagner, 2003;
243 Chalmers and Fabricius, 2007). All rehabilitation sites were then visited initially with
244 the village mangrove expert to record site history, reasons for the previous
245 degradation, history of the rehabilitation effort(s), planting dates, details of site
246 preparation, silvicultural practice and species choice. Site details recorded included
247 presence / absence of trees, presence / absence of natural regeneration (indicating
248 whether a site might naturally regenerate on its own) and hydrological connectivity.
249 Also recorded were site elevation (section 2.2.3), soil type (sand, silt or clay),
250 presence of standing water and post-hoc interventions such as the use of fencing. In
251 addition other factors likely to affect rehabilitation and plant establishment were
252 noted, such as evidence or presence of grazing livestock or trampling damage. Soil
253 salinity was measured either from available soil pore water or groundwater sourced
254 from minor excavations up to 15cm deep (Bellingham and Stanley handheld
255 refractometer). However, it should be noted that it was not always possible to
256 measure salinity in some of the high mangrove zone assessments because of a lack
257 of available soil water. This might have skewed the resulting analysis. The direction
258 of this potential skew is uncertain. The locations of the boundaries of all the
259 rehabilitation sites were recorded via a handheld GPS (Garmin 62stc). Subsequently
260 these GPS waypoints were employed to calculate the area of each site using Google
261 Earth Pro. All site features were photographed.

262 Because several sites were planted more than once, a distinction has been made
263 between 'attempt' (n = 119) and 'site' (n = 74). Wherever possible, all previous
264 attempts on the same site were evaluated (38% of assessments) as well as the final
265 (or only) attempt on a site (62%). Seventy-five of the attempts were in Thailand, 44
266 in the Philippines. The majority of the rehabilitation sites were <0.3 ha, ranging from
267 0.001 – 50 ha (SD \pm 7.73 ha). The cumulative total area assessed was 164 ha.

268 **2.2.2 Mangrove Establishment: Counts, Extrapolations and Area Calculations**

269 Although there are a range of factors that could be measured when assessing
270 rehabilitation (see Dale et al., 2014 for a review), propagule or seedling survival is an
271 unequivocal measure of whether the plants had managed to establish and survive or
272 not. Presence or absence of natural regeneration was noted at the time of
273 assessment - distinguishable from planted material by not being in lines, unevenly
274 spaced, without canes and often of a pioneer species - but which did not contribute
275 to survival scores. Plant health and vigour was also noted at the time of assessment.
276 Three techniques were used to assess survival depending on different planting ages
277 and types of sites.

278 Preferentially, we used a 'full count' method for more recent planting events as both
279 Thai and Philippine villages usually used canes which indicated where planting
280 material had been inserted. Planting was frequently conducted in straight lines and
281 even spacing. Therefore, for more recent planting projects (i.e. less than 1-2 years
282 old) in less exposed sites, missing or absent plants were immediately obvious due to
283 the resulting gap left in the lines of plants. Where possible every plant was counted
284 for each generation of planting (if applicable). However, ten large-scale planting
285 attempts were too extensive to allow each surviving plant to be counted. These

286 extensive sites were stratified by elevation, exposure and channel edge / interior.
287 Sub-plots were assessed to incorporate all significant variation of a site in order to
288 achieve a minimum sample of at least 10% of the surviving plants.

289 Where full count inventory was not possible, we extrapolated counts from surviving
290 patches of planting to the whole site. Some rehabilitation sites were too small or too
291 fragmented to justify planting in lines. If present, surviving patches indicated how
292 densely the site had been planted originally. In combination with a site history and
293 the opinion of the village expert, total numbers planted were estimated and
294 contrasted with survivors present, to produce a survivorship percentage for each
295 generation of planting (if applicable).

296 In some cases, particularly on mudflat sites, there was often little trace of planting
297 activity, or insufficient survivors to assess survivorship either via the 'full count'
298 method or by extrapolation of surviving patches. Therefore we asked the village
299 expert and participants of the planting to indicate as accurately as possible the
300 boundary of the planted area, which was then marked by GPS. We then counted
301 every surviving plant within this defined planting area. Subsequently Google Earth
302 Pro was used to determine the area of the planting site. The stated planting
303 spacing, normally 2x2m, was then used to calculate numbers originally planted. By
304 dividing the number of surviving plants by the estimated number that had originally
305 been planted, a survivorship percentage could be produced. For example, a
306 planting area described by the village expert, marked by GPS, drawn as a polygon
307 on Google Earth Pro might be revealed to cover 10 ha. If the stated planting density
308 was 2x2 m spacing, this area would have originally had 25,000 plants. If the
309 survivors counted within this defined planting area numbered 500, the survivorship
310 was 2%.

311 These three different methods of survivorship assessment engendered different
312 levels of confidence. To reconcile possible differences between methods, a post-hoc
313 resampling was conducted using the extensive field photography to reassess all 74
314 sites. On the assumption that the 'full count' method produced the most accurate,
315 bias-free estimate of survival, we recalibrated 'extrapolation from surviving patches'
316 against the 'full count'. This post-hoc reassessment suggested that there was only a
317 minor under-estimation of survival at low levels of survival, and a corresponding
318 minor over-estimation of survival at higher levels of survival. Therefore, once
319 reconciled, all three data sets were subsequently treated in the same manner. 'Full
320 count' method was used for 38% assessments, 'extrapolation from surviving
321 patches' 52% and 'counts within a defined area' 10% of attempts.

322 **2.2.3 Mangrove Zones and the Quality of the Hydrological Connection**

323 On any of the sites examined, several biotic and abiotic gradients were potentially
324 affecting where mangroves lived, resulting in distinct bands of species. Most
325 influential among these factors was the frequency and duration of a site's inundation
326 due to its elevation relative to sea level (van Loon et al., 2016). Following Duke
327 (2006) and Tomlinson (2016), bands of mangrove species were classified into three
328 zones. The 'low' zone, which started at approximately mean sea level, received
329 inundation at high tides >45 times a month and was characterised by species such
330 as *Sonneratia alba* and *Avicennia alba*. 'Mid' zones were inundated by normal high
331 tides 20 to 45 times a month and were the home of *Rhizophora* spp. and *Ceriops*
332 *tagal*. 'High' or 'back' zones received inundation <20 times a month at high tide and
333 included back mangrove species such as *Heritiera littoralis*, *Lumnitzera* spp.,
334 *Scyphiphora hydrophyllacea* and *Acrostichum* spp. Mudflats, which normally

335 occurred between lowest water and mean sea level, were inundated by every high
336 tide.

337 Table 2 illustrates the distribution of rehabilitation attempts within these mangrove
338 zones. Most rehabilitation or afforestation attempts were on mid mangrove areas
339 (52%), mudflats (30%), together with high zone areas (13%).

340

Table 2. Frequency of rehabilitation attempt by mangrove zone, by country

		Position of Rehabilitation Attempt Relative to Tidal Inundation Regime				Total
		Mudflat	Low Zone	Mid Zone	High Zone	
Country	Thailand	7	1	52	15	75
	Philippines	29	4	10	1	44
Total		36	5	62	16	119

341

342 Mid and high zone rehabilitation sites varied greatly in hydrological connection to
343 tidal flushing, thus elevation per se was not necessarily a good indicator. Instead
344 better hydrological connection was judged by the following indicators:

- 345 • greater number of days a month the site was inundated, according to the
346 village expert
- 347 • many seeds / propagules present on the ground not directly under a potential
348 seeding tree (indicating that inundations were able to transport them onto the
349 site)
- 350 • greater presence of established mangrove natural regeneration (indicating
351 that soil drainage was adequate for plant growth)
- 352 • wet soil and other evidence of the area having been recently inundated (e.g.
353 visible tide line)

- 354 ● a lack of extensive areas of standing water (indicating better drainage and
355 suggesting a better quality of soil, as saturated soils are less well suited for
356 mangrove establishment)
- 357 ● a lack of visible salt crystals on the soil surface (indicating that sufficient
358 inundation was avoiding a build-up of salt – a stressor for all mangroves)
- 359 ● limited plant / tree stress indicators (e.g. canopy die-back, stunted plants,
360 abnormally small leaves, a proliferation of prop roots on *Rhizophora* sp.)
- 361 ● fewer dead leaves on the ground (indicating that they had been washed
362 away)
- 363 ● no significant debris within the channels, e.g. from cutting for charcoal
364 production (debris would slow water flows, inhibit the distribution of seeds and
365 propagules and increase the chance of sedimentation within the channels)

366 A qualitative decision was made by weighting all the above criteria equally. We
367 classified each site's hydrological connectivity as either 'good' or 'partial / poor'
368 based on the preponderance of indicators of good connection compared to indicators
369 of poor connection. Mudflats and lower mangrove elevations by definition have good
370 connectivity to the local hydrology and therefore were not assessed for the quality of
371 their hydrological connection.

372 **2.2.4 Time Since Planting**

373 One hundred and nineteen attempts at mangrove rehabilitation or afforestation were
374 evaluated over 74 sites. Of these attempts 36 were assessed less than 12 months
375 after planting. We attempted to achieve a balance between including the maximum
376 amount of data possible yet avoiding false-positives by excluding planting that had
377 not yet had sufficient time to either establish or fail to establish. The cut-off was set
378 at one year. The exception to this cut-off period was planting attempts where

379 survivorship was $\leq 5\%$ (14 planting attempts) as the planting within these attempts
380 had already clearly failed. Therefore 97 attempts were retained for analysis.

Table 3. Time between planting and assessment, by frequency of rehabilitation attempt

Time between Planting Attempt and Assessment	All Attempts Assessed	Planting Attempts Retained for Further Analysis
< 1 Year	36	14
13 – 24 Months	29	29
> 2 Years	54	54
Total	119	97

381

382 **2.2.5 Criteria for Judging Whether Planting was Required**

383 An assessment was made as to whether each mangrove rehabilitation site might
384 have regenerated naturally, whether rehabilitation should never have been
385 attempted at that site, or whether planting was necessary and appropriate. Whether
386 planting was necessary and appropriate or not was assessed by the following
387 indicators:

- 388 ● an absence of natural regeneration and / or a lack of successful establishment
389 of natural regeneration
- 390 ● appropriate site elevation for mangrove establishment relative to sea level,
391 and resulting inundation regime, (i.e. within either low, mid or high mangrove
392 zones, with duration and frequency of flooding, as described in section 2.2.3.).
393 Mudflats, extending from approximately mean sea level down to lowest water,
394 hydrological channels and areas of standing water were deemed
395 inappropriate places for planting and ecologically unsuitable for mangrove
396 establishment (Lewis, 2005)
- 397 ● low expected wave energy (the assumption was that young plants that were
398 subject to significant wave energy will be damaged or uprooted and washed

399 away.) Assessment included evidence of erosion, whether the site was
400 directly open to the sea and the opinion of a local mangrove expert

- 401 ● soil mechanically firm enough to anchor a propagule or seedling
- 402 appropriately, not so soft as to allow the researcher to sink into the mud up to
- 403 the knees
- 404 ● minimal levels of significantly-sized debris on site (which might be lifted by the
- 405 tide and damage vulnerable plants)
- 406 ● no inhibiting social factors such as uncontrolled animal grazing, boat impact,
- 407 damage from footfall or destruction from the use of damaging fishing gear
- 408 which scrapes along the sediment surface uprooting natural regeneration

409 A qualitative decision was made by weighting all the above criteria equally, and
410 classifying each site as either requiring planting, able to naturally regenerate on its
411 own, or an inappropriate site that will never become mangrove, based on the
412 preponderance of indicators described above.

413 **3. Results**

414 **3.1 Site Descriptors and Demographics for All 119 Attempts**

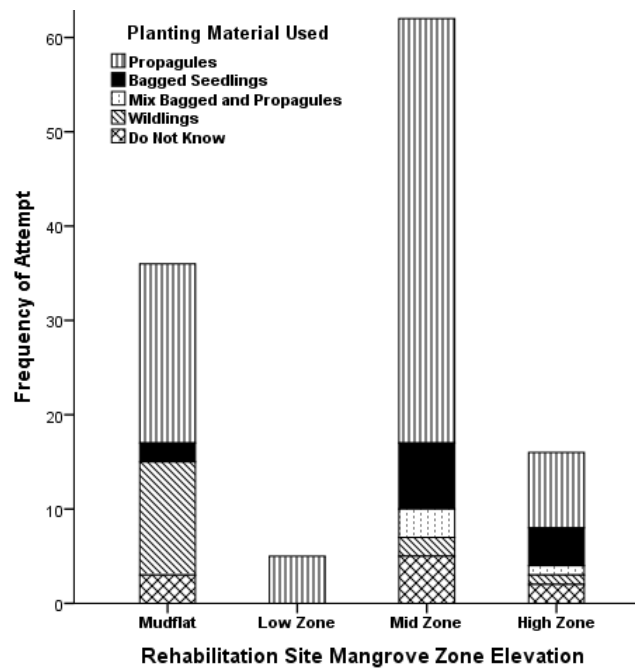
415 Hydrological connection, by definition, was complete for mudflats and low zone
416 mangroves. However, for mid and high mangrove zones, some only had partial /
417 poor connection and drainage (section 2.2.3) with a limited exchange of water at
418 each tidal flushing, and areas of standing water. Of all the attempts within mid and
419 high mangrove zones (n = 80) only a quarter (26%) had a good hydrological
420 connection. There was no evidence that any measures had been taken to improve
421 hydrological connection in those sites with partial / poor connection. Occasionally,
422 hydrology was made worse (e.g. village T2A), by skimming the grass off a site with a
423 bulldozer during site preparation, thereby filling the drainage channels in the
424 process. On other sites, previous tree felling for charcoal had left brush and debris
425 in the channels (e.g. village P1A), slowing the flow of water and increasing
426 sedimentation in the channels.

427 High and mid zone mangrove soil salinities (both 27ppt, SD ± 2 and SD ± 8
428 respectively) were slightly less than low zone salinity (33ppt, SD ± 2.3), which in turn
429 was less than sea water (normally approximately 35ppt). Partial / poor hydrology
430 appeared not to affect average mangrove soil salinity as much as the presence of
431 fresh water input from rivers flowing into mangrove deltas.

432 A majority of rehabilitation attempts (65%) 'direct planted' propagules into the soil.
433 Thirteen percent of attempts (all in the Philippines) used 'wildlings', young plants with
434 2-5 leaf pairs, pulled out of their original location and transplanted as bare-root stock.
435 Eleven percent of rehabilitation attempts used polybagged seedlings. Rehabilitation
436 was left to natural regeneration in only two instances, which have been included in

437 the analysis because using this form of rehabilitation was a conscious decision on
438 the part of the village (T2A) conservation group.

439 Fig. 1 illustrates in which zone the different types of planting material were used.
440 This broad distribution suggests there was little relationship between planting
441 material used and site elevation. Direct planting of propagules was the most
442 common across all species except *Nypa fruticans*.



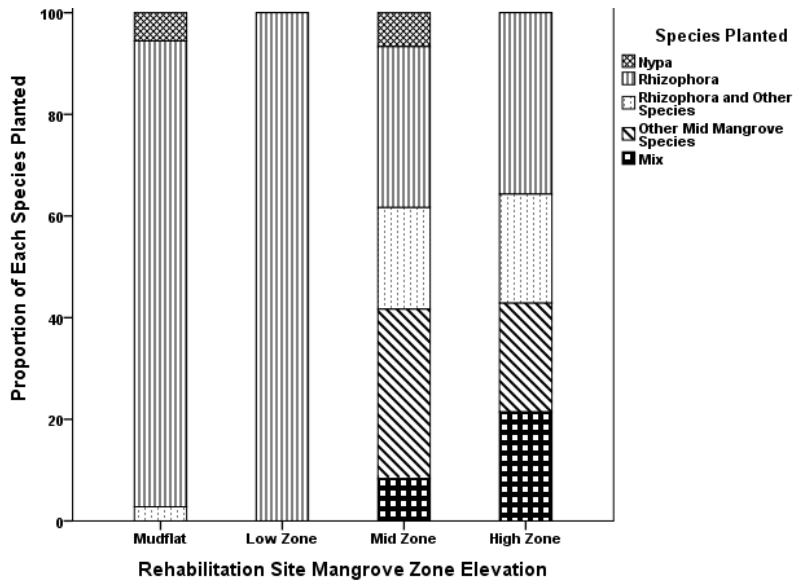
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444

445 **Fig. 1.** Frequency of mangrove zone planted, by planting material used.
446 (Natural regeneration has been excluded for clarity.)
447

448 By species, *Rhizophora* spp. was used in the majority of planting; alone in 52% of
449 attempts and in conjunction with other mid mangrove species (e.g. *Ceriops tagal*,
450 *Bruguiera* spp.) another 13% of the time.

451 Other mid mangrove species such as *Ceriops tagal* and *Bruguiera* spp. were planted
452 19% of the time (Fig. 2) . 'Mix' (n = 6) denotes when a selection of (rarely more than
453 three) species was used from more than one mangrove zone. These often but not
454 always included *Rhizophora* spp., along with *C. tagal*, *Bruguiera* spp. and very

455 occasionally mangrove associate *Pandanus tectorius* (Kitamura et al., 1998;
456 Tomlinson, 2016).



457
458

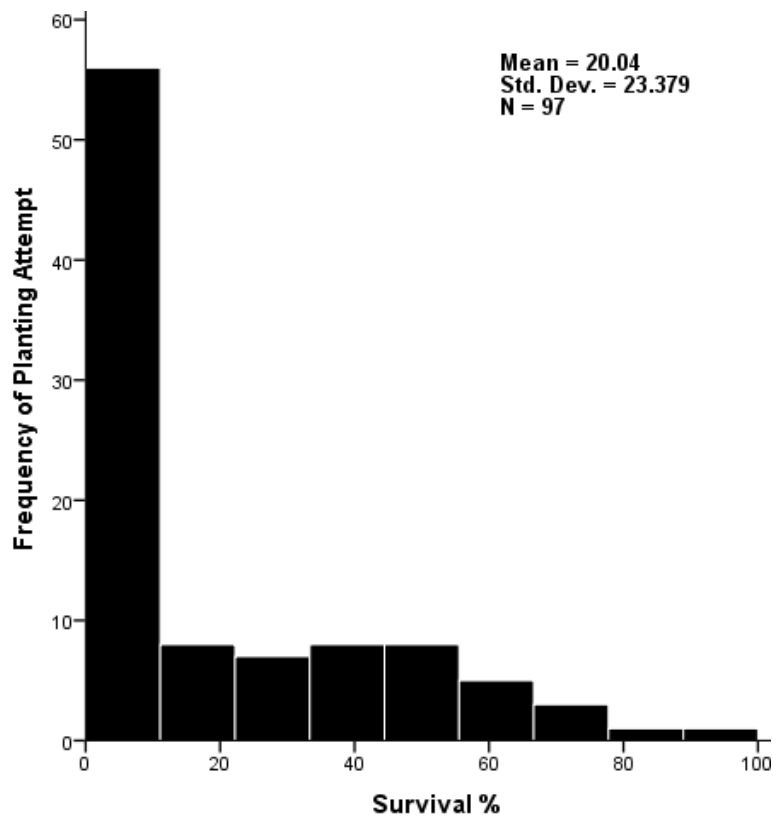
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461

Fig. 2. Proportions of mangrove species used by mangrove zone.

462 **3.2. Rehabilitation Successes and Failures**

463 All analyses from this point onwards excludes the 22 attempts assessed as ‘too
 464 recent to judge’ (section 2.2.4) unless otherwise stated. For this reduced subset of
 465 rehabilitation attempts (n = 97), the mean survival rate was 20% (SD ±23.4) with a
 466 median of 10%, Fig. 3, the median or middle score being less affected by a non-
 467 normal or skewed distribution of data and extreme scores (Field, 2018).



468
469

470 **Fig. 3.** Percentage survival rates by frequency.
471

472 The difference between 13-24 month and > 2-year planting survivorship was not
 473 significantly different (p = 0.54), indicating that most propagule death occurred within
 474 the first year after planting, Table 4.

Table 4. Mean survivorship by time between planting and assessment

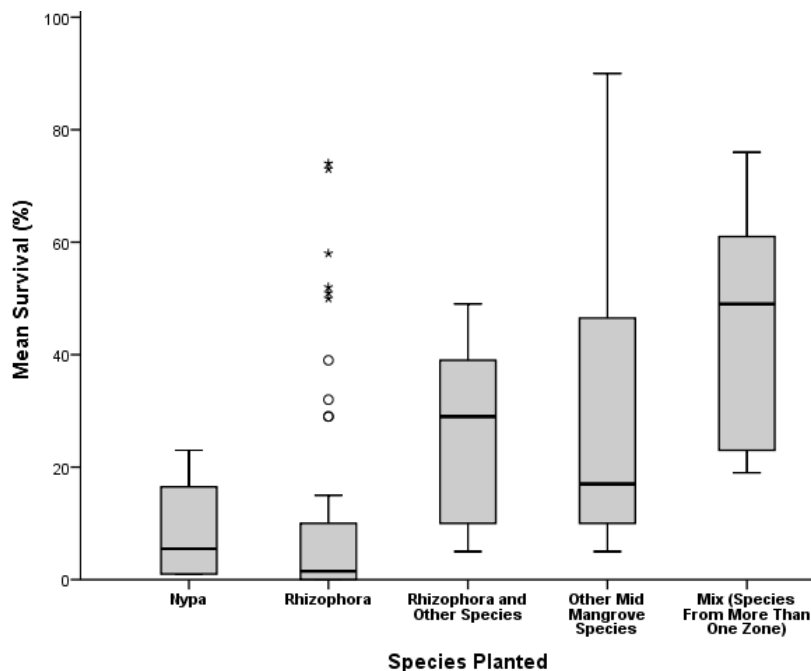
Mean Survivorship by Time Between	< 1 Year	13-24 months	> 2 Years	Total
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Planting and Assessment				
Mean Survival %	1.6	23.9	22.8	
SD	2	27.4	22	
N	14	29	54	97

475

476 Mean planting survival varied significantly ($p < 0.001$) between Thailand (26%, SD
 477 ± 24.3 , $n = 58$) and the Philippines (11%, SD ± 18.8 , $n = 39$). This reflected a
 478 tendency to attempt to afforest mudflats in the Philippines. The mean survival for
 479 mudflats was low (1.4%, SD ± 3.6 , $n = 31$) compared to mid mangrove zones (30.1%,
 480 SD ± 22.5 , $n = 48$) or high mangrove zones (25%, SD ± 28.3 , $n = 13$). Salinity
 481 exhibited a significant inverse relationship with planting survivorship ($p < 0.001$).

482 Fig. 4 shows the survival rates by mangrove species. The mean survival rate of
 483 *Rhizophora* spp. was 11% (SD ± 20.4 , $n = 50$), despite being the most popular choice
 484 for planting. The establishment of *Nypa fruticans* was similarly poor (9%, SD ± 10.4 ,
 485 $n = 5$). Other mid-mangrove species fared better with a mean survival of 29% (SD
 486 ± 26.8 , $n = 20$), as did 'Mix' (i.e. a range of species from more than one mangrove
 487 zone, 46.2%, SD ± 22.8 , $n = 6$).



488

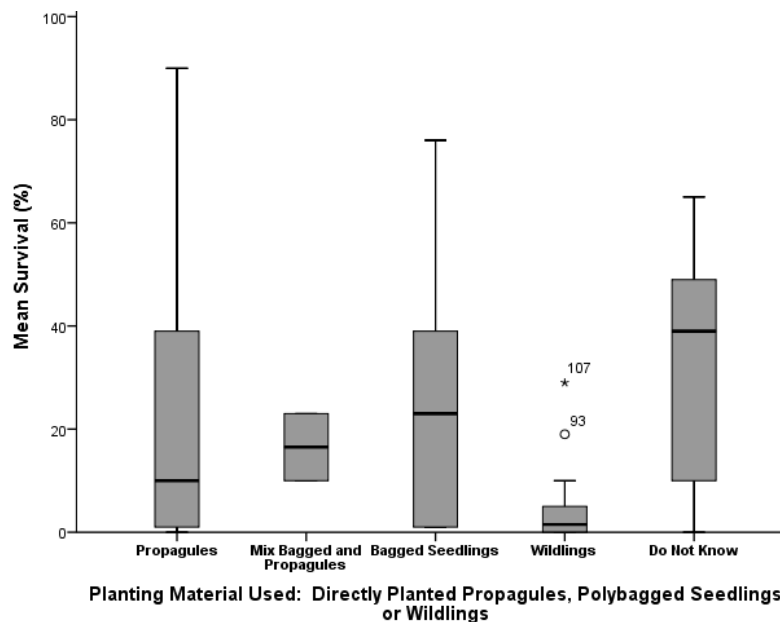
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491

Fig. 4. Survival rates by species planted.

492 While there was no significant difference in survival between directly planted
493 propagules and bagged plants, ($p = 0.32$), there was a significant difference between
494 propagules and wildlings ($p = 0.024$), and between bagged plants and wildlings, ($p =$
495 0.022), Fig 5.

496 Bagged plants (mean survival 27.6%, SD ± 26.6 , $n = 9$) were either *Nypa fruticans*,
497 *Ceriops tagal* or very occasionally mangrove associate *Pandanus tectorius*.

498 Otherwise, planting was 'direct planting' of propagules into the substrate (mean
499 survival 20.2%, SD ± 23.9 , $n = 62$). Transplanted 'wildlings' (bare root stock, always
500 *Rhizophora* spp., mean survival 5.4%, SD ± 8.6 , $n = 14$) were only used in the
501 Philippines.



502
503

Fig. 5. Planting survival by type of planting material used.

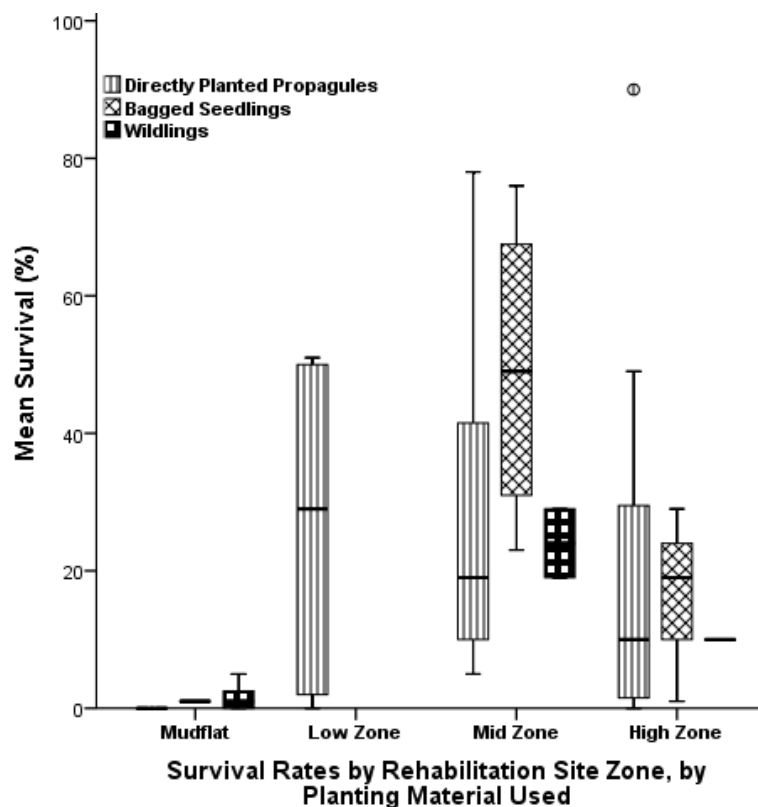
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505

506 Within the mid and high zone mangrove areas, mean survival of planted material
507 was significantly lower ($p = 0.038$) in sites with partial / poor hydrological connection

508 at 24.8% (SD ±21.9, n = 48), compared to areas with good hydrology where the
509 survival rate was 39.9% (SD ±26, n = 15).

510 3.3 Interactions Between Factors

511 Table 2 shows that mudflats and mid mangrove elevations were frequently chosen
512 as sites for afforestation / rehabilitation planting. Mudflats proved resistant to
513 planting whatever form of planting material was employed. However, mid and high
514 zone sites had better survival of all planted materials, and bagged plants (n = 9) in
515 particular, Fig. 6.

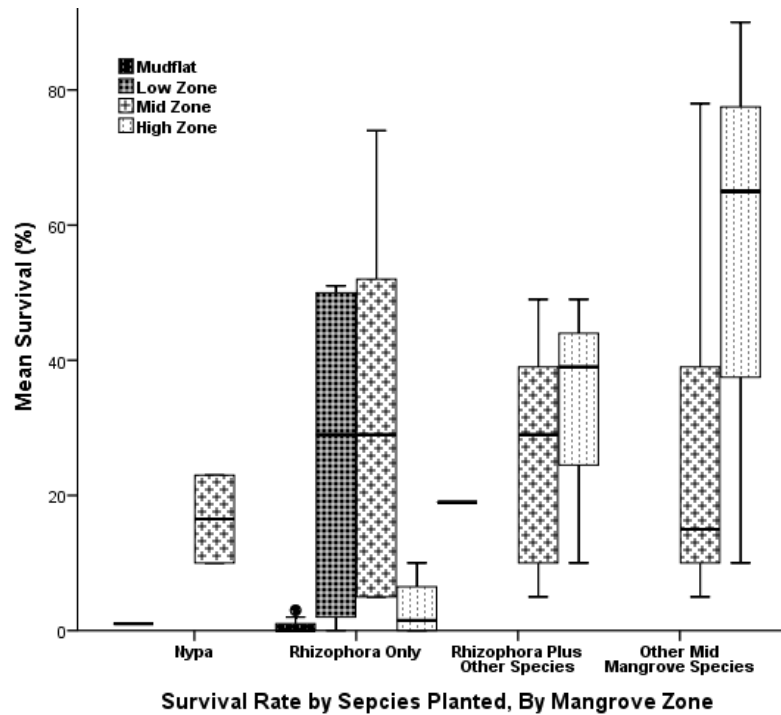


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518 **Fig. 6.** Planting survival by mangrove zone, by planting material.
519 (Planting material category 'Don't Know' (n = 10) and 'Mixed' (n = 2) have been omitted for clarity.)
520

521 Fig. 2 (section 3.1) indicated the proportions of different species used for planting, at
522 differing elevations. Fig. 7 illustrates that on mudflats and in back mangrove zones,
523 *Rhizophora* sp. (n = 52) was not an appropriate genus to use. However, when

524 *Rhizophora* sp. was used in zones suitable for this genus (low and mid zones), its
 525 survival rate improved but was no more successful than 'Other Mid-Mangrove
 526 Species' (n = 21) which was only used in mid-to-back elevations. *Nypa fruticans* (n
 527 = 5) also performed poorly on mudflats.



528
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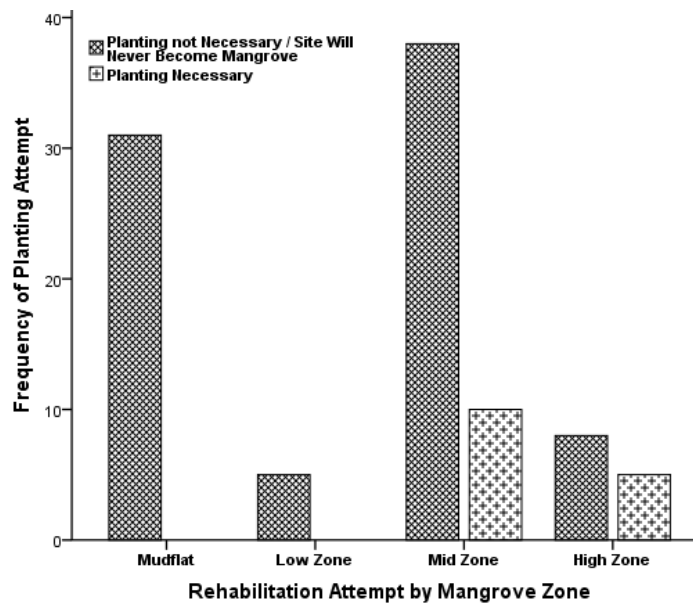
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Fig. 7. Survival of species planted by mangrove zone.
 (Mixed species (n = 6), natural regeneration (n = 2) have been omitted for clarity.)

533 **3.4 Was Planting Necessary?**

534 Planting survivorship was significantly higher ($p < 0.001$) when natural regeneration
535 was present on a rehabilitation site (mean survival 26.3%, SD ± 20.6 , $n = 51$)
536 compared to when there was no natural regeneration present (mean survival 13%,
537 SD ± 24.4 , $n = 46$).

538 Using the criteria described previously (section 2.2.5) natural regeneration would
539 have been sufficient, and planting unnecessary in 37% of attempts, largely within
540 mid and back mangrove zones. Another 47% of attempts 'will never be mangrove'
541 because of inappropriate hydrology or being located at an unsuitable inter-tidal
542 elevation. For clarity of depiction, these two categories have been combined in Fig. 8
543 to contrast against the 16% of planting attempts that were considered to have been
544 necessary, by mangrove zone.



545
546

547 **Fig. 8.** Frequency of unnecessary/inappropriate planting against necessary planting, by mangrove zone.
548

549 **4. Discussion**

550 **4.1 Research Method Limitations**

551 More sites were assessed in Thailand than in the Philippines. Where possible,
552 information from the village expert was cross-checked against interviews with
553 government mangrove agency field office staff, villagers, and by direct observation,
554 to reduce recall error.

555 Plant health, vigour and biomass characteristics were not included in survivorship
556 assessment, but were taken into account for the quality of hydrological connection,
557 the appropriateness of the site and species choice, and whether or not a site
558 required planting. This inevitably involved an element of judgement and site
559 interpretation, and consideration of factors such as the frequent seasonal floods in
560 southern Thailand and watershed-scale hydrological disturbance in villages T3A and
561 T3B (Osbeck et al., 2010; Prabnarong and Kaewrat, 2006), or the reduction of
562 precipitation due to the 'El Nino Southern Oscillation' event that occurred during the
563 research period (L'Heureux et al., 2017).

564 Separating and discarding 22 planting attempts which were 'too early to judge'
565 (section 2.2.4) from those which had had 'enough time' to establish or fail, may have
566 negatively affected survivorship results, but may also have removed potential real
567 positives as well as false positives.

568 Although benchmarking against other mangroves (McDonald et al., 2016) might
569 have been suitable in countries where there is pristine mangrove nearby, Thailand
570 and the Philippines have very little mangrove which has not been replanted after
571 charcoal / fuelwood concessions, subjected to species-selective felling or had natural
572 *Sonneratia* / *Avicennia* forests replaced by *Rhizophora* spp. planting, such as in

573 Banacon Island, Philippines, or Pak Phanang Bay, Thailand (Macintosh et al., 2002;
574 Osbeck et al., 2010; Walters, 2005). Mangrove workers who have suggested that
575 rehabilitation projects should aim for and be judged by ecological rehabilitation
576 criteria (Asaeda et al., 2016; Ellison, 2000; Lewis, 2000; Walters et al., 2008) are by
577 implication working towards the conditions which allow the return of full ecosystem
578 function (Saenger et al., 2013). Although appropriate in theory, using such criteria
579 presents a practical problem as a result of the extensive time needed between
580 planting and full recovery of ecosystem function. To have a chance of returning an
581 area to functioning mangrove forest, the initial planting must first survive any
582 transplant shock and establish itself. The data presented here only describe this
583 initial establishment. We acknowledge that planting which might become established
584 and grow into a new stand and might therefore be deemed successful, could still
585 potentially fail to deliver the full suite of ecosystem benefits. Examples of this later
586 failure include mangroves used to stabilise the walls of aquaculture ponds but which
587 have little hydrological connection, or when mangroves are planted in drainage
588 channels which block the local hydrological connection, leading to eventual
589 ecosystem failure.

590 **4.2 Discussion of the Results**

591 The majority of sites that would probably have recovered through natural
592 regeneration alone were mid and back mangrove, Fig. 8. Within these zones, some
593 areas viewed by the villagers as 'degraded' were simply mangroves with natural
594 gaps and desirable forest complexity. However, because they were seen as
595 degraded they were re-planted, which sometimes included clearing biodiverse
596 natural regeneration and 'crown lifting' of existing non-*Rhizophora* sp. trees (Walters,
597 2004). Only a few sites that had previously been mangrove before being cleared or

598 degraded, normally for charcoal, were not regenerating (16%). Typically, this was
599 due to poor hydrology, hard smooth soil making the retention of 'volunteer'
600 propagules / seeds difficult or for other reasons such as a lack of fencing to keep out
601 grazing animals (Field, 1996). In these cases planting was necessary and might
602 ultimately facilitate quicker mangrove succession (Ferreira and Lacerda, 2016; Lewis
603 et al., 2016), but with no guarantee of success because the other site-specific
604 mangrove stressors, discussed here and in section 2.2.5, were often not resolved.

605 If planted sites would have regenerated on their own, without planting intervention as
606 demonstrated by Lewis (2005) and Brown et al. (2014), this could avoid planting
607 costs and liberate financial and labour resources for other management tasks.

608 Generally, the presence of natural regeneration is a good indicator that a potential
609 site is suitable for rehabilitation. However, natural regeneration can also start to
610 establish in hydrological channels following the failure of the local hydrology.

611 Similarly, although some of the mudflat afforestation attempts were situated near the
612 fringe of existing mangrove, and hence were interspersed with a limited amount of
613 pioneer species natural regeneration, this did not mean that these sites were
614 potential mangrove areas. In short, open mudflats and mangrove drainage channels
615 (47% of 97 attempts) were not ecologically appropriate sites, and rehabilitation /
616 afforestation should not have been attempted in these locations.

617 The mangrove zone within the inter-tidal range runs from above mean sea level
618 (Alongi, 2002; Kairo et al., 2001; Lewis, 2005) or upper third (Saenger, 2002) to
619 highest high water. Knowledge of mangrove species zoning is essential for
620 successful rehabilitation (Kairo et al., 2001). So-called site / species matching has
621 been offered as a key reason for planting failure – i.e. planting inappropriate species
622 for a given site and its inherent conditions (Alongi, 2002; Aung et al., 2011; Bosire et

623 al., 2006; IUCN, 2017; Kodikara et al., 2017; Primavera and Esteban, 2008;
624 Saenger, 2002; Walters et al., 2008). The failure to improve planting performance
625 despite increased financial spend by NGO-led projects in the Philippines (Samson
626 and Rollon, 2008; Walters, 2008) or the 1bn Peso (£14m) 'National Greening
627 Programme' in the Philippines (Ranada, 2015) is in part due to the frequent planting
628 of mid zone *Rhizophora* sp. in all zones (Fig. 2). This is possibly because its
629 propagules are easy to collect and handle and do not require growing-on in a
630 nursery (Lewis, 2014; Primavera, 2015; Primavera et al., 2011; Primavera and
631 Esteban, 2008). The research described here demonstrates the improved success
632 rates associated with planting the correct species for the specific mangrove zone
633 (Fig.7).

634 While acknowledging the challenges of hydrological assessment (van Loon et al.,
635 2016), an understanding of site hydrology, topography and drainage, and the effects
636 these have on salinity and the species chosen, is vital for successful mangrove
637 rehabilitation (Aung et al., 2011; Elliott et al., 2016; Elster, 2000; Hashim et al., 2010;
638 Kairo et al., 2001; Lewis, 2005; Oh et al., 2017). Some sites can be restored simply
639 by hydrological reconnection or improvement if propagules are available from nearby
640 stands via hydrochory (Prach and del Moral, 2015; Stevenson et al., 1999). Unlike
641 Elster's Colombian experience (2000) and Brown et al., (2014) in Indonesia,
642 hydrology was rarely considered at our study sites, having been discussed only once
643 at one Thai site (village T3A). Occasionally site hydrology was made worse by
644 inappropriate site preparation. This study has documented the significant difference
645 improved / adequate hydrology makes to rehabilitation success. This therefore
646 suggests that many of the mid and back mangrove sites would have benefited from
647 improved hydrological connectivity and drainage. However, guidelines for hydrologic

648 rehabilitation are sparse and communication between researchers and mangrove
649 managers appears to have been insufficient to change rehabilitation activities.

650 Although there was no significant difference in the survival rates of directly planted
651 propagules and bagged seedlings (Fig. 5), extrapolation of these results should be
652 done with caution. Bagged seedlings tended to be *Ceriops tagal* and *Nypa fruticans*
653 not *Rhizophora* sp. and were likely to be used in a more appropriate zone (Fig. 6).
654 However, planting of bagged *N. fruticans* on mudflats resulted in total mortality
655 (village T3B). Bagged material was only deployed if it was provided by the
656 government, rather than for ecological or silvicultural reasons and used much less
657 often than direct planting of propagules (section 3.1). Excluding special cases, the
658 resulting small sample sizes were too small to make further analysis appropriate.

659 Clump planting propagules close together (i.e. < 30cm apart) to allow planted
660 material to benefit from a mutually improved rhizosphere (Chan and Baba, 2010;
661 Lavieren et al., 2012) was never attempted. Root-balled 'wildlings' were not
662 attempted by any group. Bare-root wildlings were only used in the Philippines,
663 where villagers and government staff believed they were more reliable than
664 propagules. Contrary to this local belief, bare-root wildlings were significantly less
665 likely to establish than other planting material (Fig. 5). However, because these
666 wildlings were most frequently deployed on mudflats, their very low survival (mean =
667 5.4%) also found by Primavera et al. (2011), cannot definitively be ascribed to bare-
668 root wildlings being an intrinsically poor silvicultural method. Furthermore, poor
669 handling, for example allowing exposed roots to dry out in direct sunlight before
670 being re-planted, cannot be ruled out. Poor survival of directly planted propagules
671 might also have resulted from propagules being collected from trees before maturity,

672 and planters having only a partial understanding of the effects of pests such as
673 *Poecilips fallax* beetle on propagules.

674 Protection from storms and strong winds is often a key motivator for mangrove
675 planting and afforestation, particularly in the Philippines where village planting was
676 funded by the 'National Greening Programme' (Department of Environment and
677 Natural Resources, 2016). In the medium-term, the rehabilitation projects described
678 here will produce densely stocked, even-aged plantations with limited structural
679 complexity. This lack of complexity should be a cause for concern as research has
680 shown that older plantation stands of *Rhizophora* spp. are more vulnerable to strong
681 winds than other species. Furthermore, they have a poor ability to recover from
682 storm damage because they lack latent buds and cannot re-grow from the base
683 when the stem is damaged (Bosire et al., 2008; Salmo III et al., 2014; Villamayor et
684 al., 2016). In addition the smooth canopy of an even-aged class stand slows wind
685 less than a mixed-aged stand of uneven height (Villamayor et al., 2016). Structural
686 complexity is characterised by a number of forest attributes such as basal area, tree
687 height, tree species, tree density, biomass, foliage arrangement, canopy cover and
688 understory (McElhinny et al., 2005). This complexity develops over time but could be
689 accelerated through planting a diversity of species at a variety of spatial densities.

690 In order to implement the 'National Greening Programme', the Department of
691 Environment and Natural Resources of the Philippines passes down extensive
692 planting area quotas to the department's field offices. To fulfil these quotas, mudflats
693 are frequently selected as they offer the necessary spatial extent (Primavera, 2015).
694 Although mudflats in both countries might have been considered silviculturally
695 inappropriate, these areas typically have uncontested land tenure (for a description
696 of the land tenure issues, see Primavera et al., 2015, 2011; Samson and Rollon,

697 2011). They are therefore easily available, as other researchers have reported
698 (Lewis and Brown, 2014; Primavera, 2015; Primavera et al., 2011; Samson and
699 Rollon, 2008; Walters et al., 2008). Thus despite evidence in the published scientific
700 literature, rehabilitation manuals and national media (Primavera, 2015; Primavera et
701 al., 2011; Ranada, 2015), planting continues on mudflats, and sometimes even
702 seagrass beds, even though mean survival rates were shown here to be <2%.
703 Mudflats are particularly valuable for feeding shorebirds, producing income for local
704 gleaners and food security (Primavera et al., 2011). Therefore on the rare occasions
705 that mudflat planting survived, normally due to rapid accretion or deposition of
706 sediment (pers. obs.), the value of substituting one ecosystem for another has been
707 questioned (Erftemeijer and Lewis, 1999; Lewis, 2005).

708 Similarly in Thailand much of the mangrove management activity was driven by
709 national propagule planting targets delegated to the mangrove agency field offices.
710 These targets originated from successive four-year National Economic and Social
711 Development Plans (for example, Office of the National Economic and Social
712 Development Board, 2011, 2001). Field offices also received additional directives
713 such as planting 840,000 propagules to celebrate a national event (National News
714 Bureau of Thailand, 2016). Furthermore there was often a general desire by villages
715 to carry out communal planting activity on national holidays. However, some field
716 offices are starting to negotiate the return of aquaculture ponds which had been
717 illegally established within the mangroves and other encroached former mangrove
718 areas. Consequently, more planting was carried out in mid and high mangrove
719 zones (section 3.1). Although the overall success rate was higher, the question
720 remains as to how much of the planting was actually necessary.

721 This paper and others (Dale et al., 2014; Lewis, 2005; Primavera and Esteban,
722 2008; Salmo III et al., 2007; Samson and Rollon, 2008;) have suggested that,
723 despite being largely unnecessary, planting has tended to dominate mangrove
724 management activity. This is typically endorsed at the national level. Area planting
725 targets set by the Philippines' National Greening Programme have produced sub-
726 optimal outcomes, and planting has also arguably received too much emphasis in
727 Thailand. Although such target-driven planting provides quantifiable measures
728 (Mansourian et al., 2017), this is unlikely to be aligned with silvicultural best
729 practices. Propagule survivorship would be a more appropriate measure, perhaps
730 combined with an emphasis on recovering abandoned aquaculture ponds. The area
731 of abandoned ponds in Thailand and the Philippines is not known, but in Indonesia
732 alone there is estimated to be around 250,000 ha (Gusmawati et al., 2017).
733 Aquaculture ponds are frequently located in mid and high zone mangrove areas
734 which this study and others have shown to be a more appropriate elevation for
735 mangrove rehabilitation. Restoring hydrological connectivity to these abandoned
736 ponds to rehabilitate them back to functioning mangrove ecosystems (Primavera et
737 al., 2011; Villamayor et al., 2016) would arguably be a more appropriate
738 management task, particularly over the coming decades as sea level rise requires
739 mangroves to retreat landward and upward (Gilman et al., 2008; Primavera et al.,
740 2011).

741 **5. Conclusion**

742 This research suggests that attention to a few key factors can enhance rehabilitation
743 outcomes. First, mangrove workers should ensure that the appropriate species are
744 planted in the mangrove zone for which they are best suited. Second, appropriate

745 hydrological connectivity with good tidal flushing and drainage improves project
746 outcomes. Third, it is suggested that much mangrove rehabilitation is either
747 unnecessary or conducted on sites which are inappropriate. Fourth, attempted
748 afforestation of mudflat sites usually fails and is not recommended. Finally,
749 rehabilitation projects should focus on survivorship rather than meeting area or
750 propagule number targets which typically produce sub-optimal outcomes.

751

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778 **7. Declaration of Interests**

779 The lead author is a volunteer for NGO Mangrove Action Project (MAP) and
780 periodically carries out paid ecological mangrove rehabilitation teaching on its behalf.
781 MAP did not contribute in any way to the funding, design, analysis or writing of this
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784 **8. Authors' Contributions**

785 Dominic Wodehouse carried out the fieldwork, analysis and the writing of the paper.
786 Mark Rayment developed the research questions, designed the research matrix,
787 contributed several data capture techniques, added to the statistical analysis and
788 edited the paper.

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790 **9. References**

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